Edge-Plasma Modeling for Liquid Walls and Divertors

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Outline

1. CLIFF design

2. NSTX module

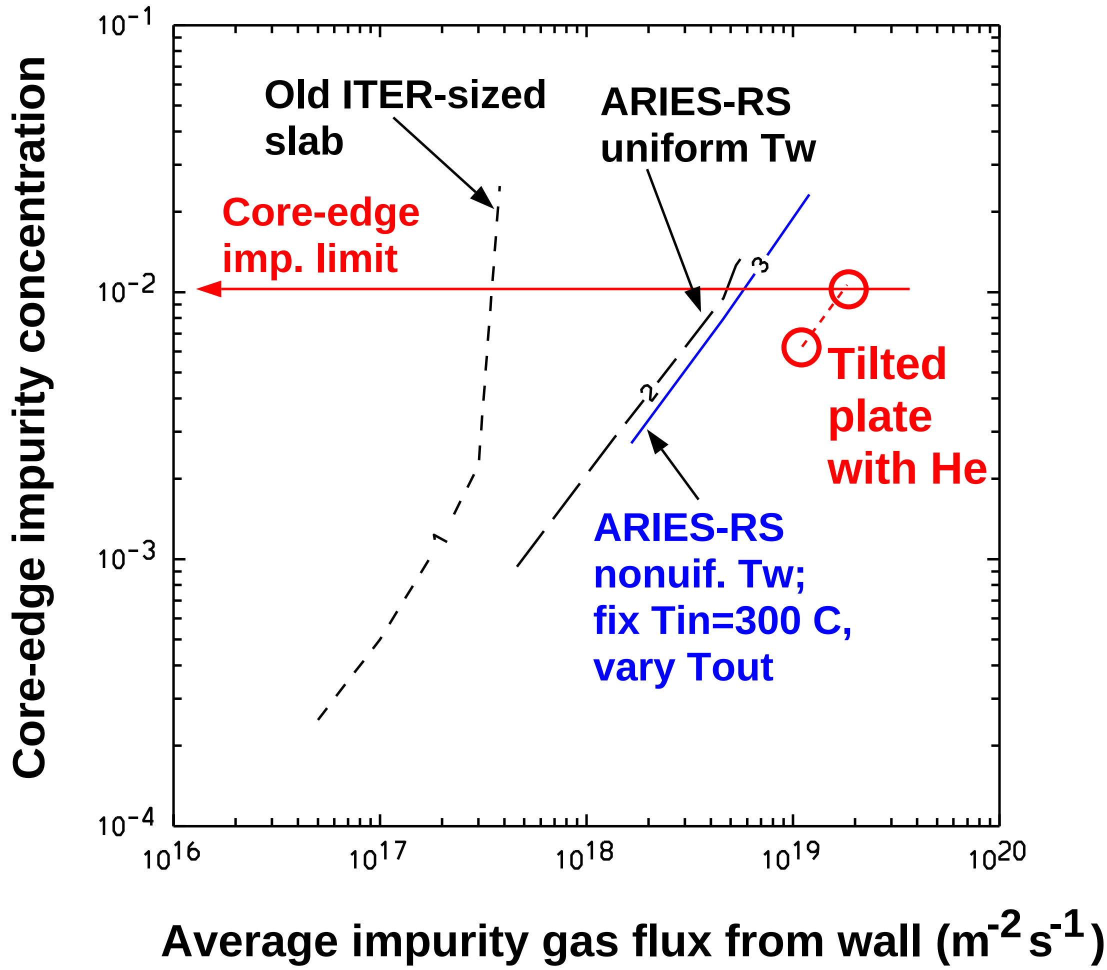
3. CDX-U lithium wall

4. Spheromak design

5. ELM SOL transport

6 3D edge-plasma code development

Wall temperature limit for flinabe (F) improves for full ARIES-RS tokamak geometry

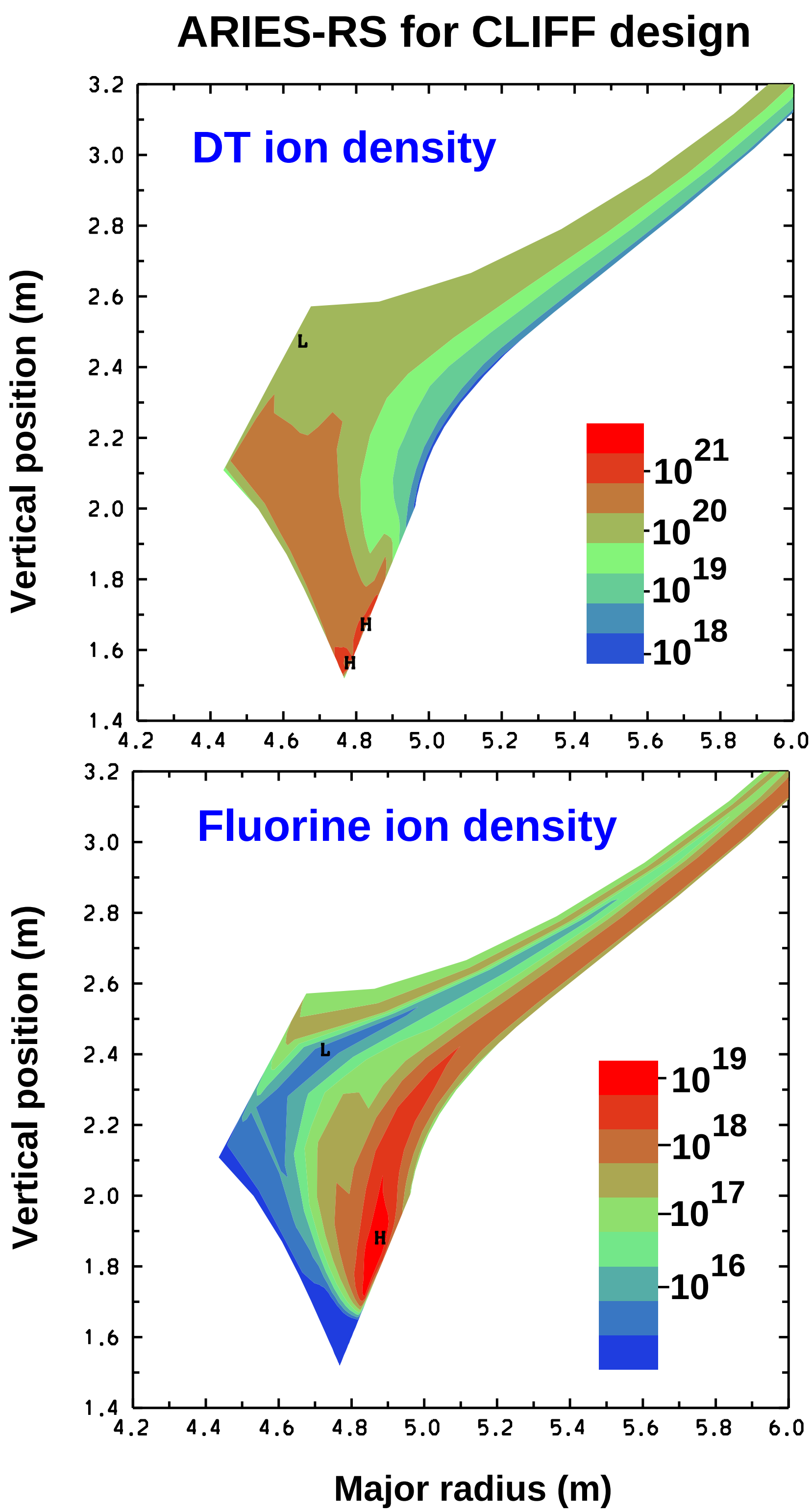


Temperature Limit Results

ITER slab: Tw = 390 C
ARIES-RS, uniform Tw: Tw = 450 C

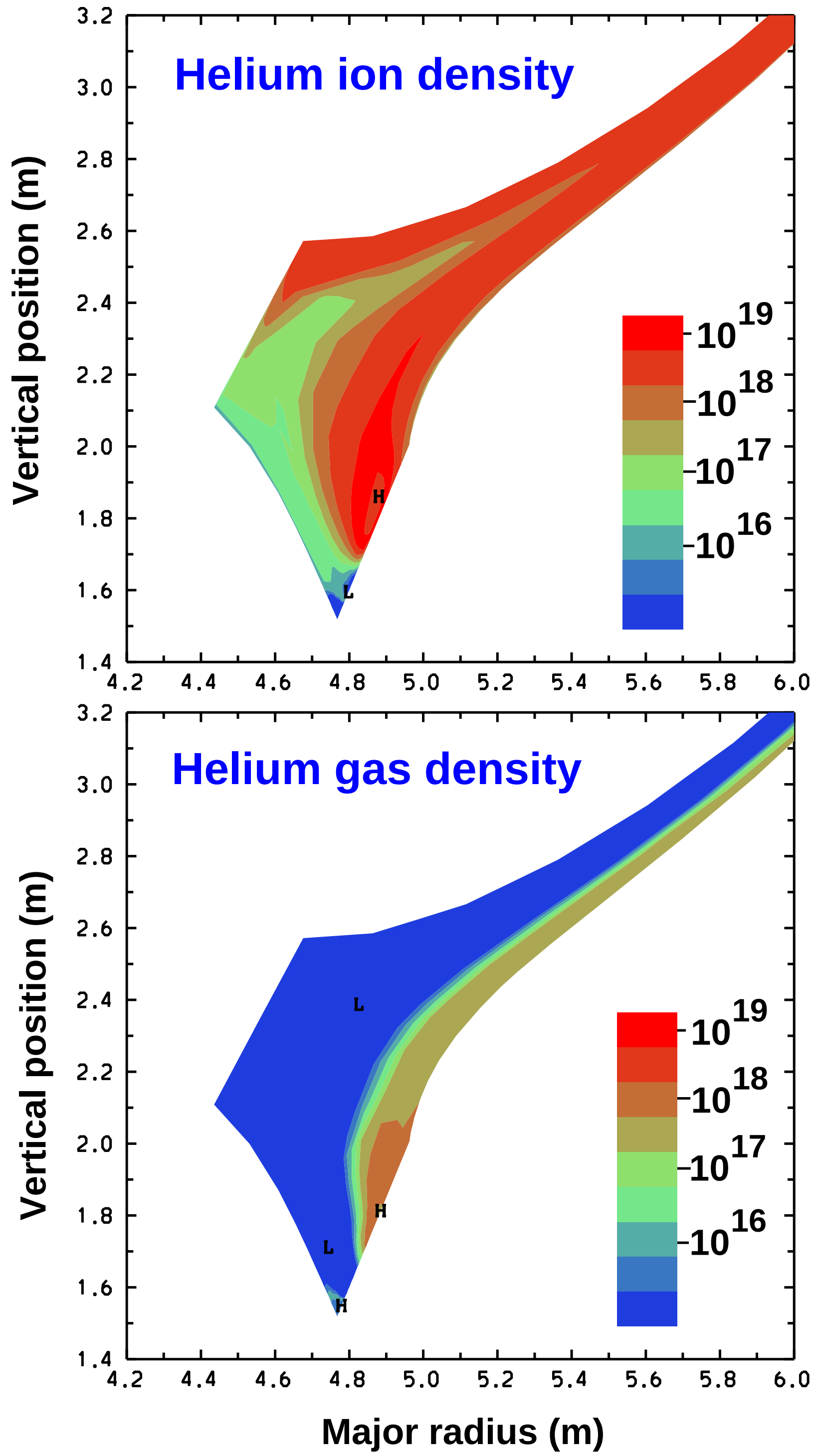
ARIES-RS, noniform Tw: Tw_in=300 C, Tw_out = 480 C
ARIES-RS, noniform Tw, tilted plate, He incl. = 515 C

Both hydrogenic and impurity densities peak near the divertor plates

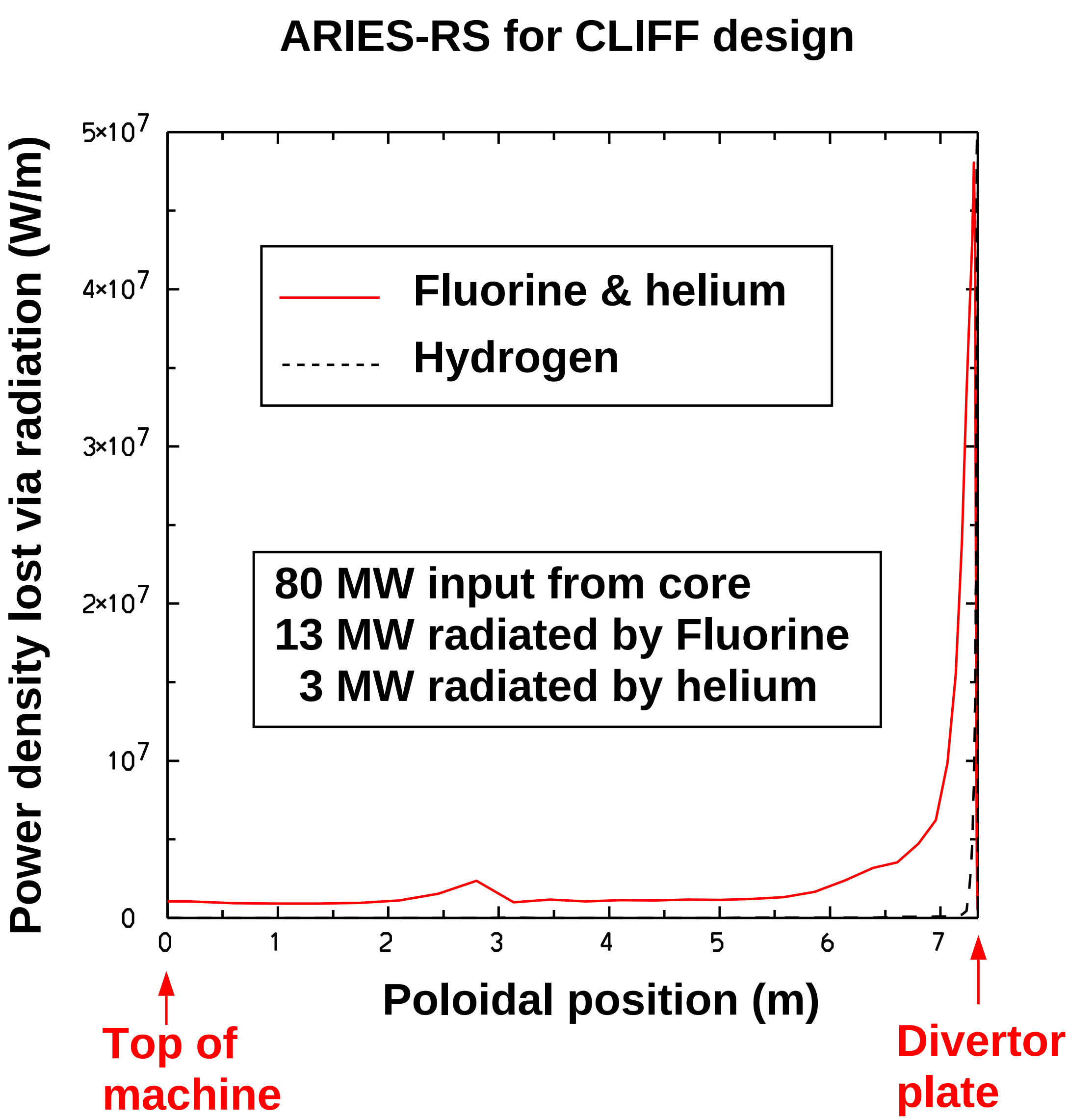


Helium ion density fairly broadly distributed, and helium gas is localized near outer plate

ARIES-RS for CLIFF design

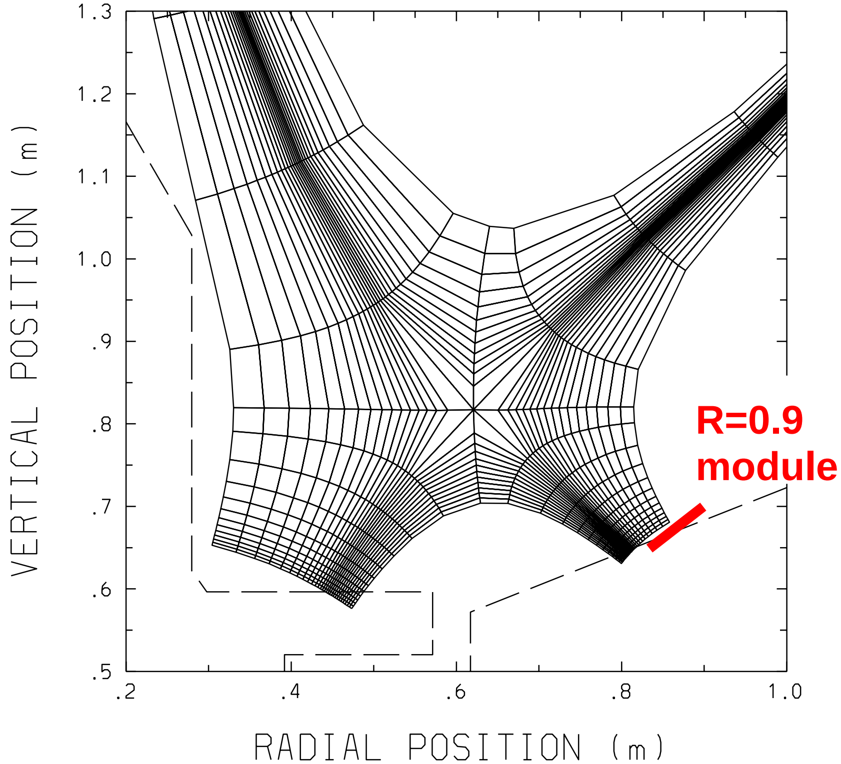


Impurity radiation is dominated by fluorine and is strongest near the divertor plate

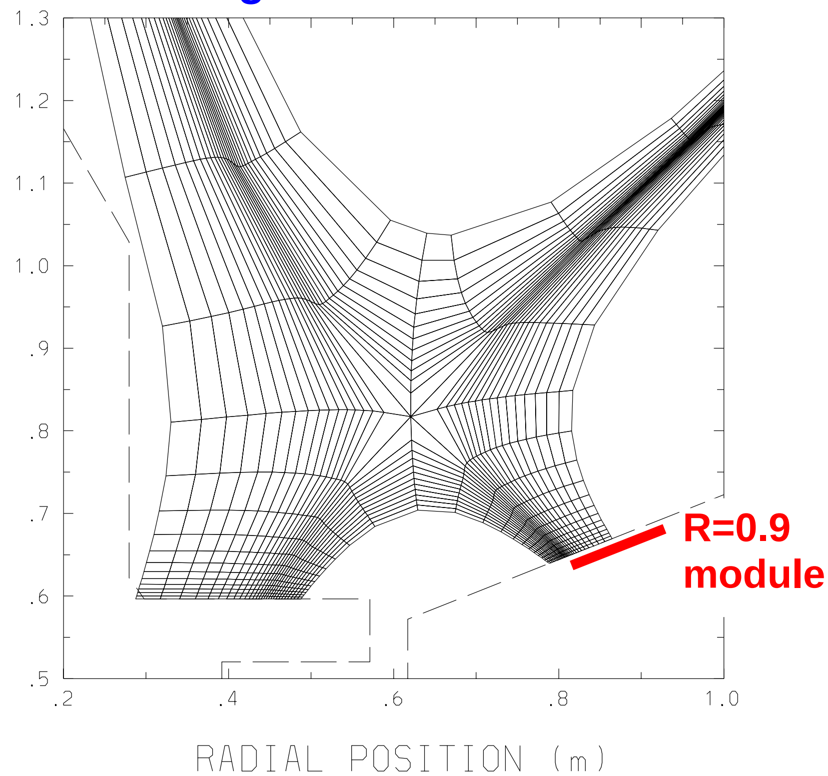


UEDGE meshes used for NSTX module modeling differ in the shape of the divertor surface (eqdsk 104312.00250)

Mesh & module perpendicular to poloidal flux surfaces

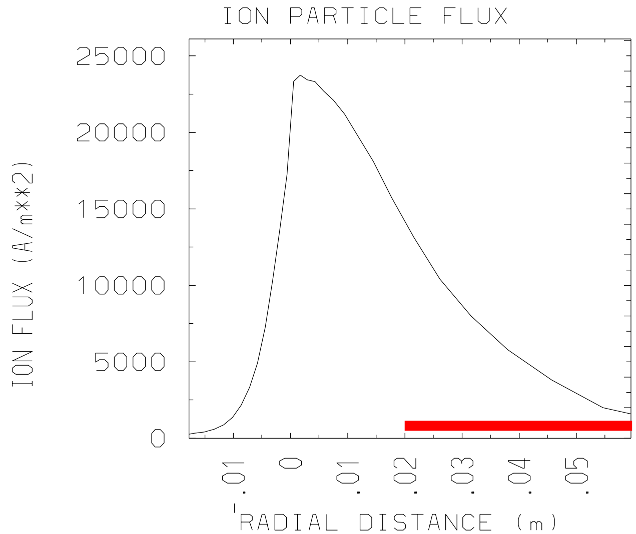


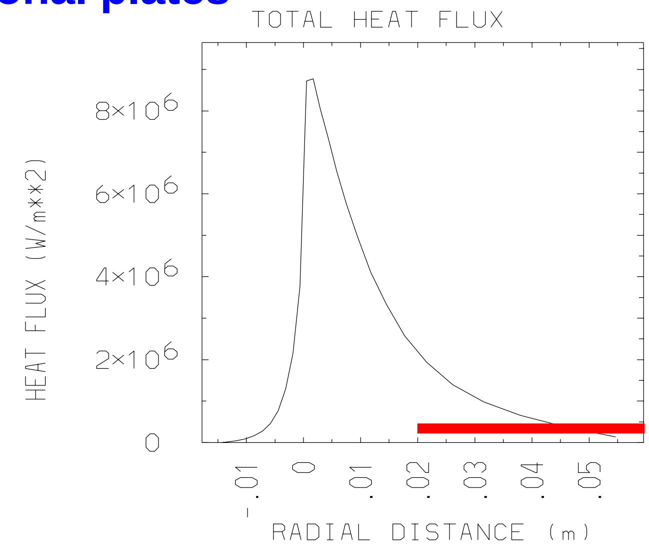
Mesh & module conform to existing divertor surfaces



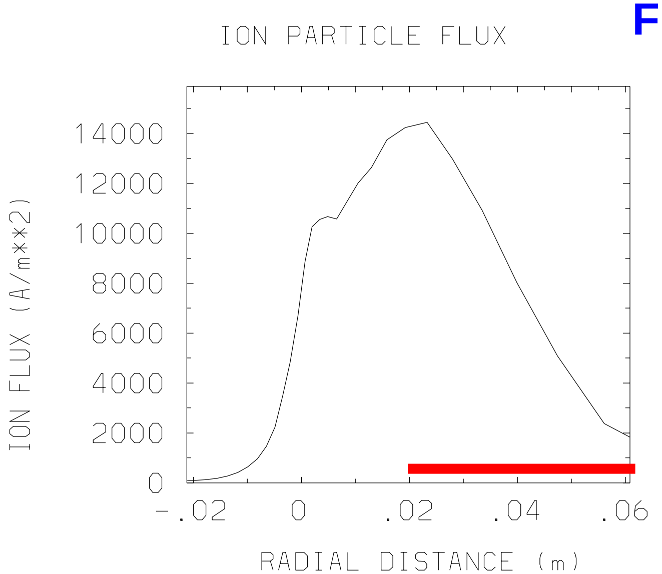
Particle and energy fluxes to plate depend on details of plate orientation

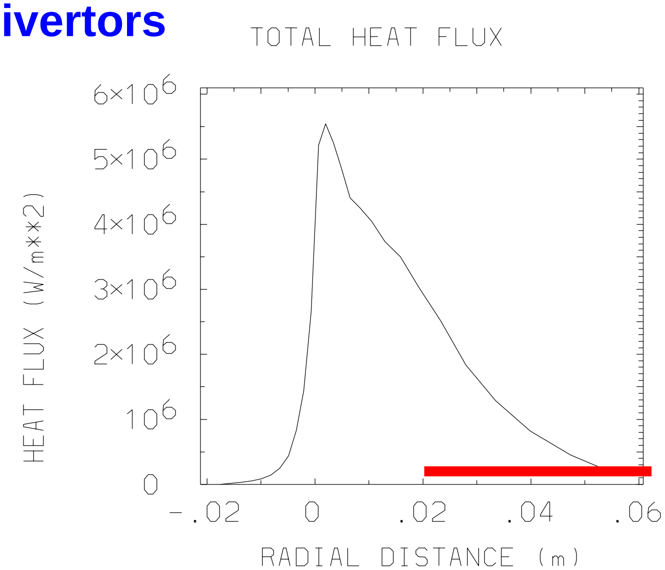
Orthogonal plates





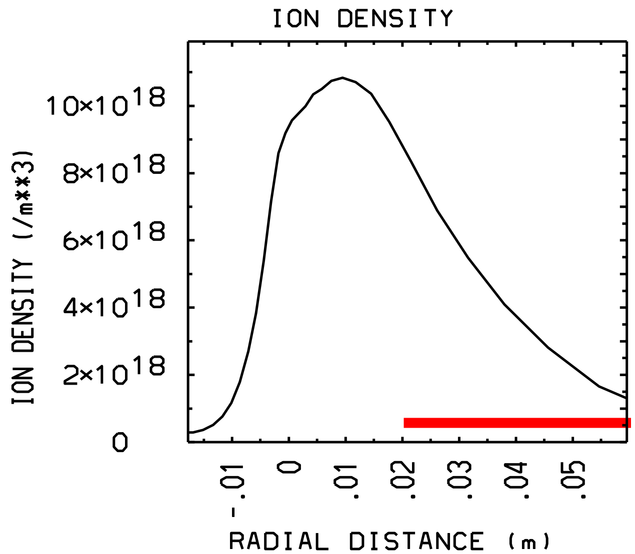
Fit to divertors

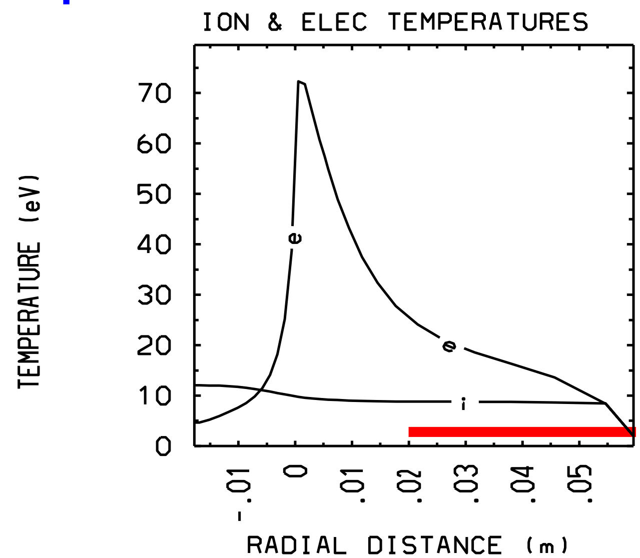




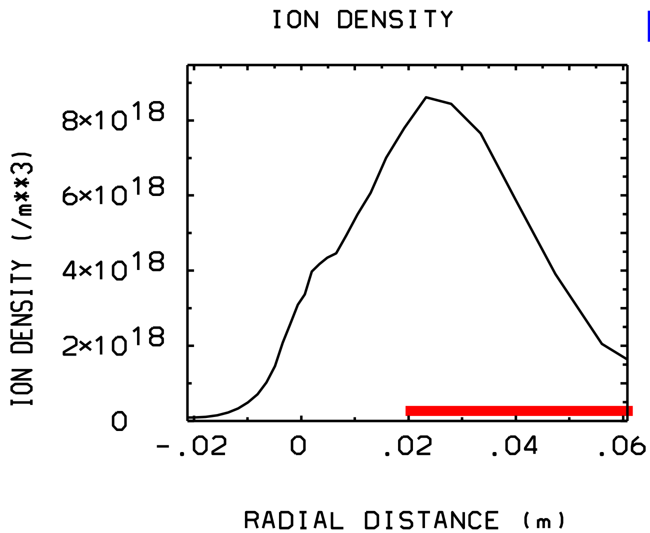
Density and temperature on outer plate depend on details of plate orientation

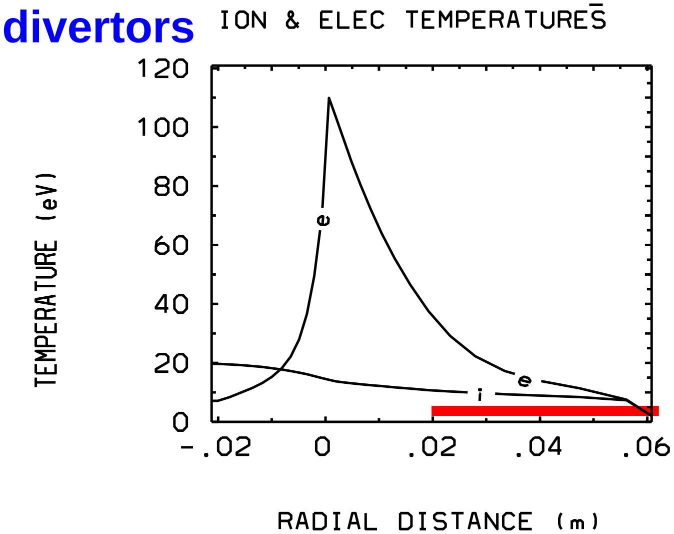
Orthogonal plates





Fit to divertors

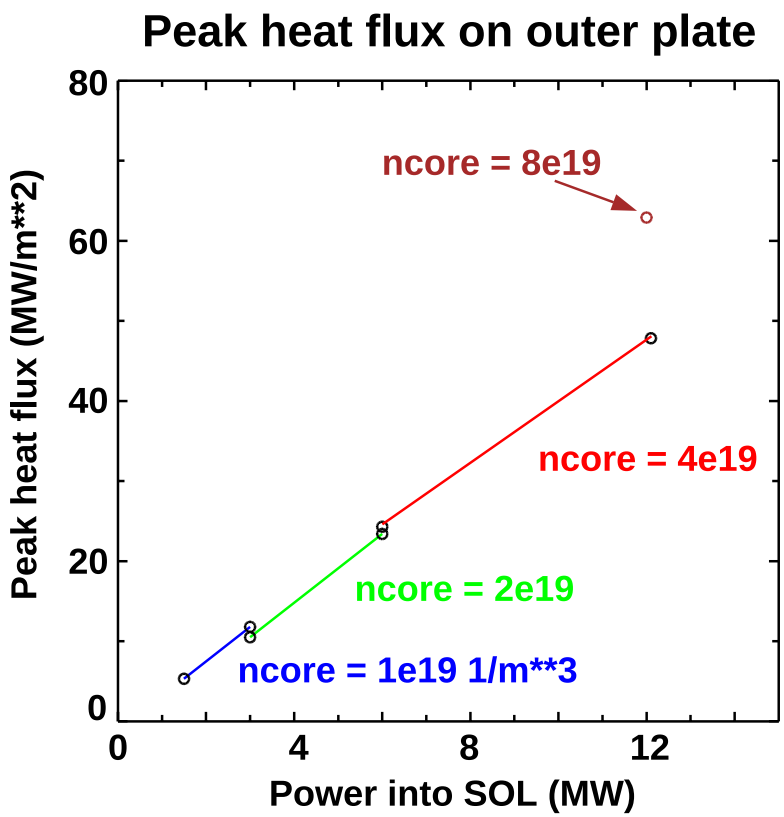


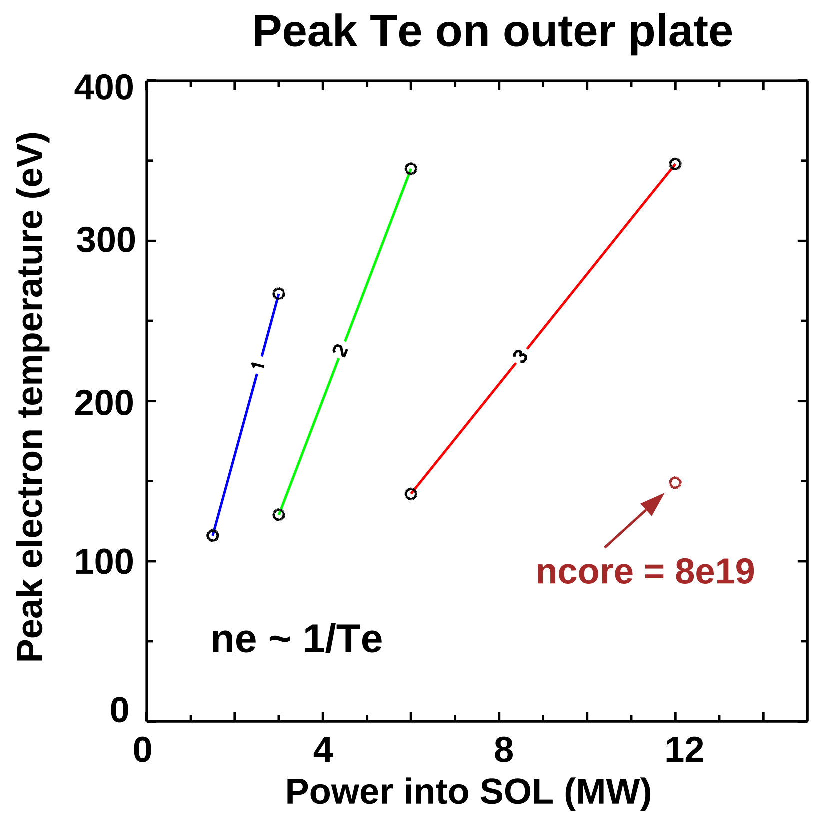


UEDGE simulations of NSTX single null with pumping module 2 cm beyond separatrix on outer plate

Various core-edge densities used as boundary conditions; n_sep ~ 0.6 ncore

Impurity radiation is neglected; module aligned to divertor plate

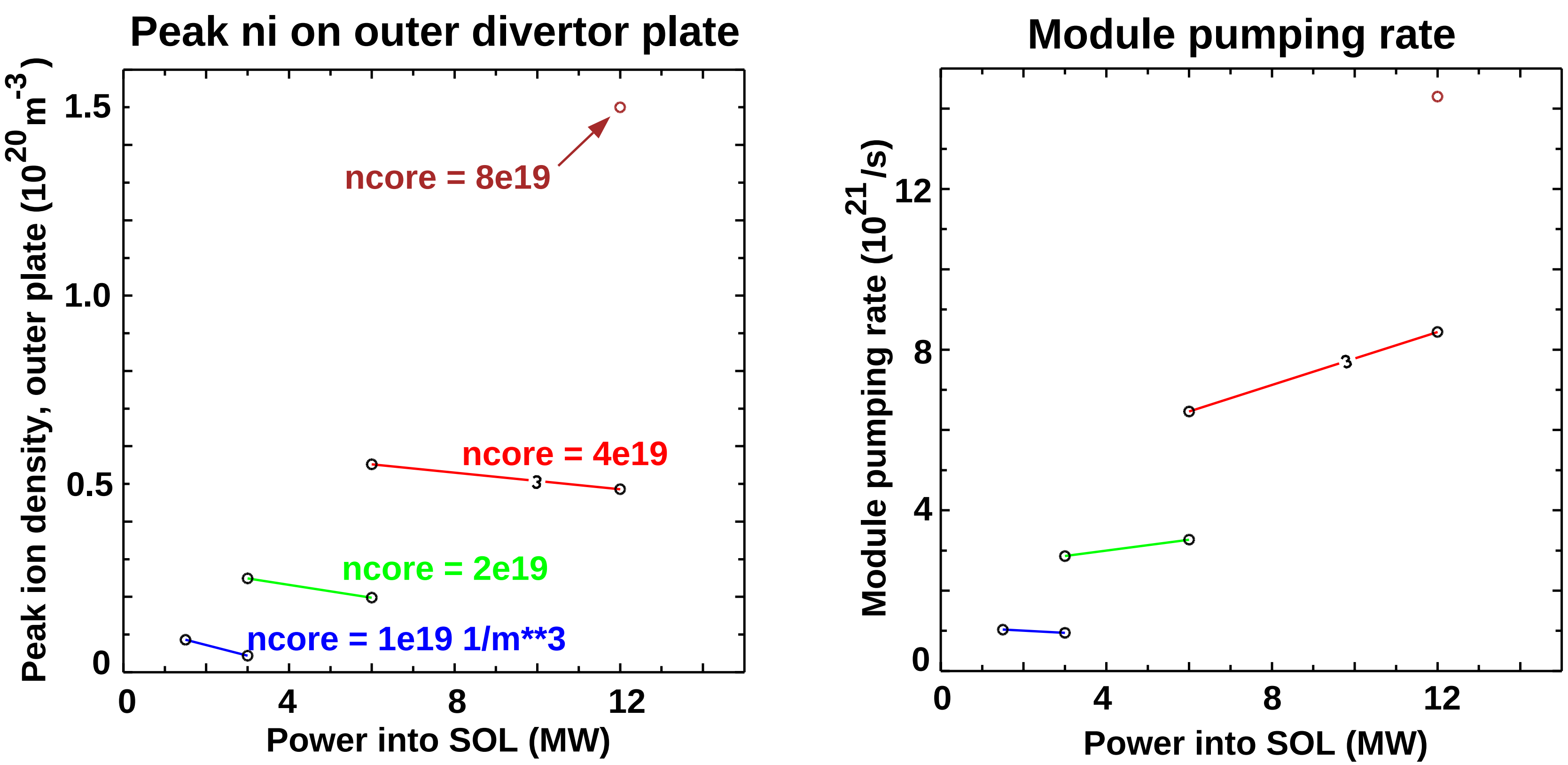




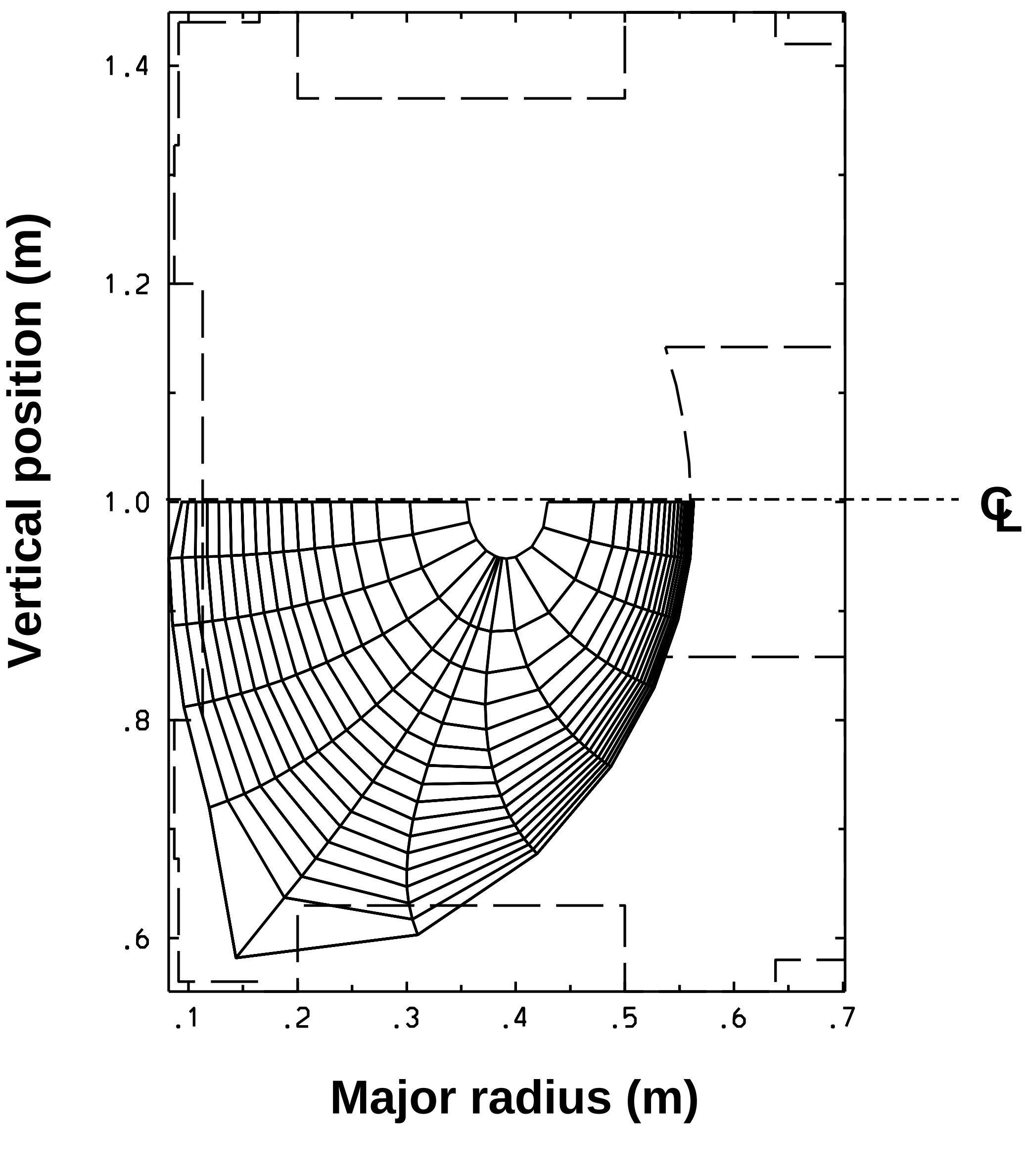
Divertor density usually about twice the separatrix density owing to the pumping module (R=0.9)

Divertor density peaks outside of Te maximum

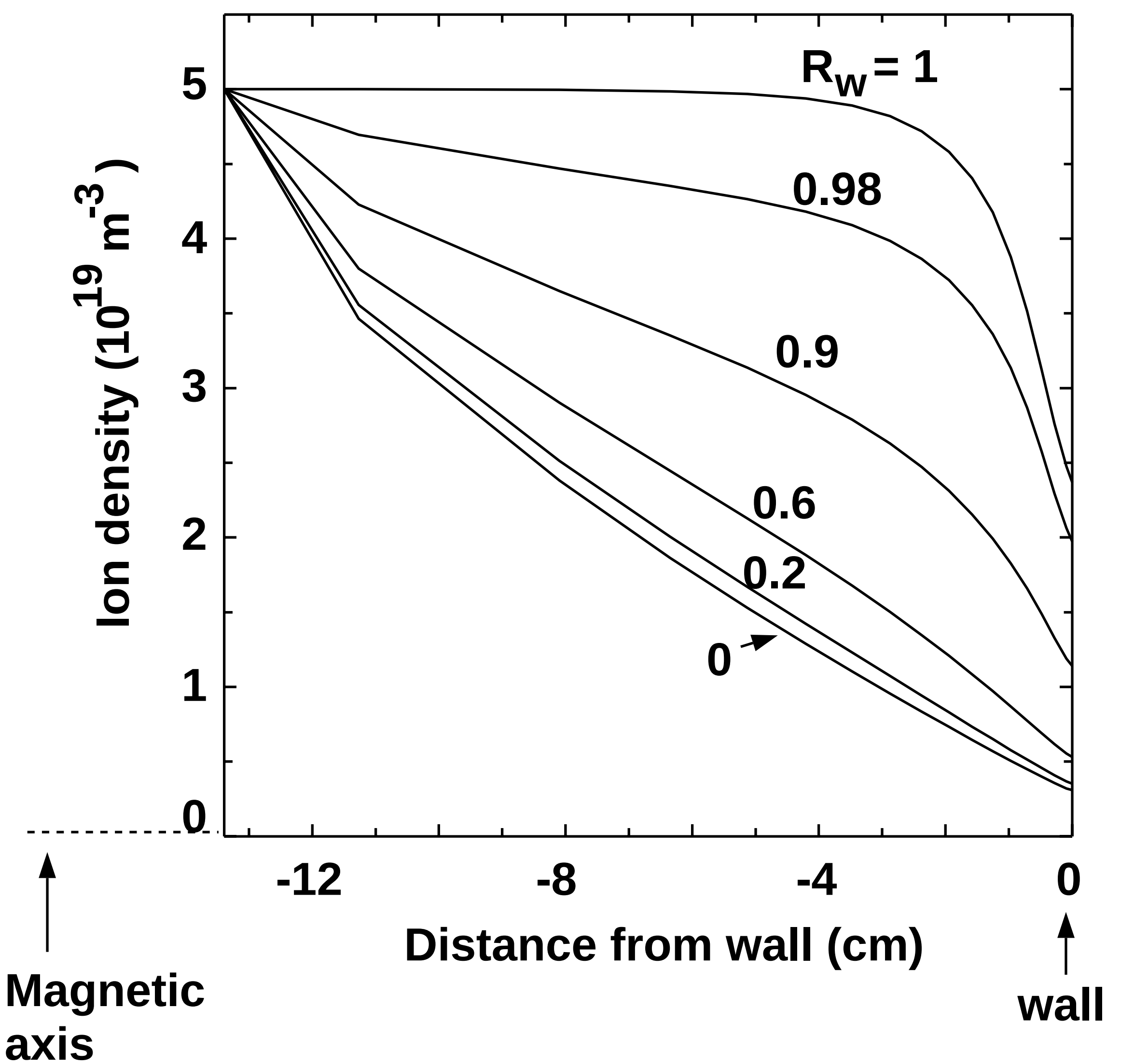
For fixed ncore, divertor density increases by factor of ~3 for no pumping



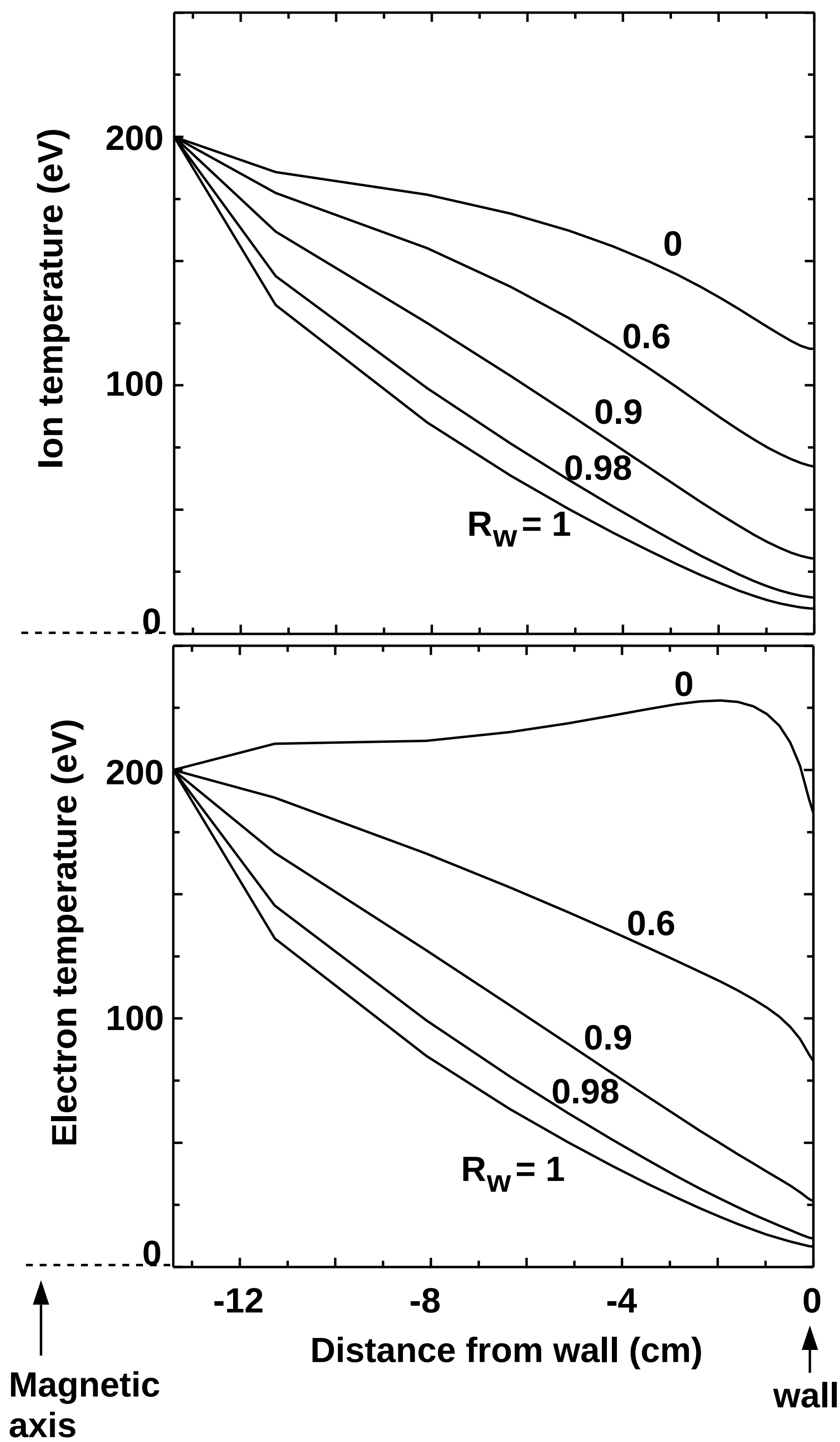
CDX-U mesh
up/down symmetry assumed



Ion density shows little change until wall recycling coefficient Rw > 0.5

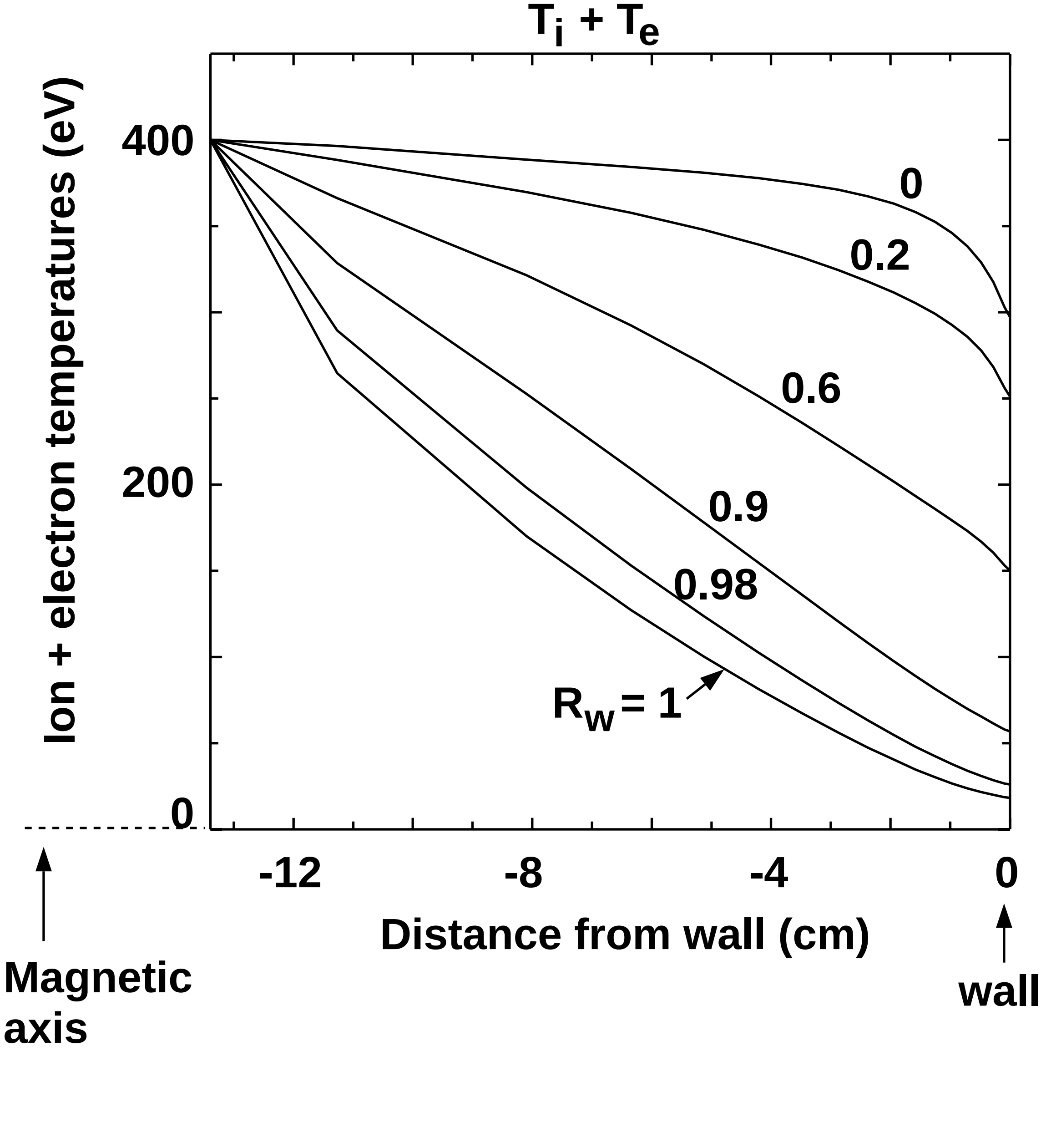


Ion and electron temperatures change inversely to ion density as Rw is varied

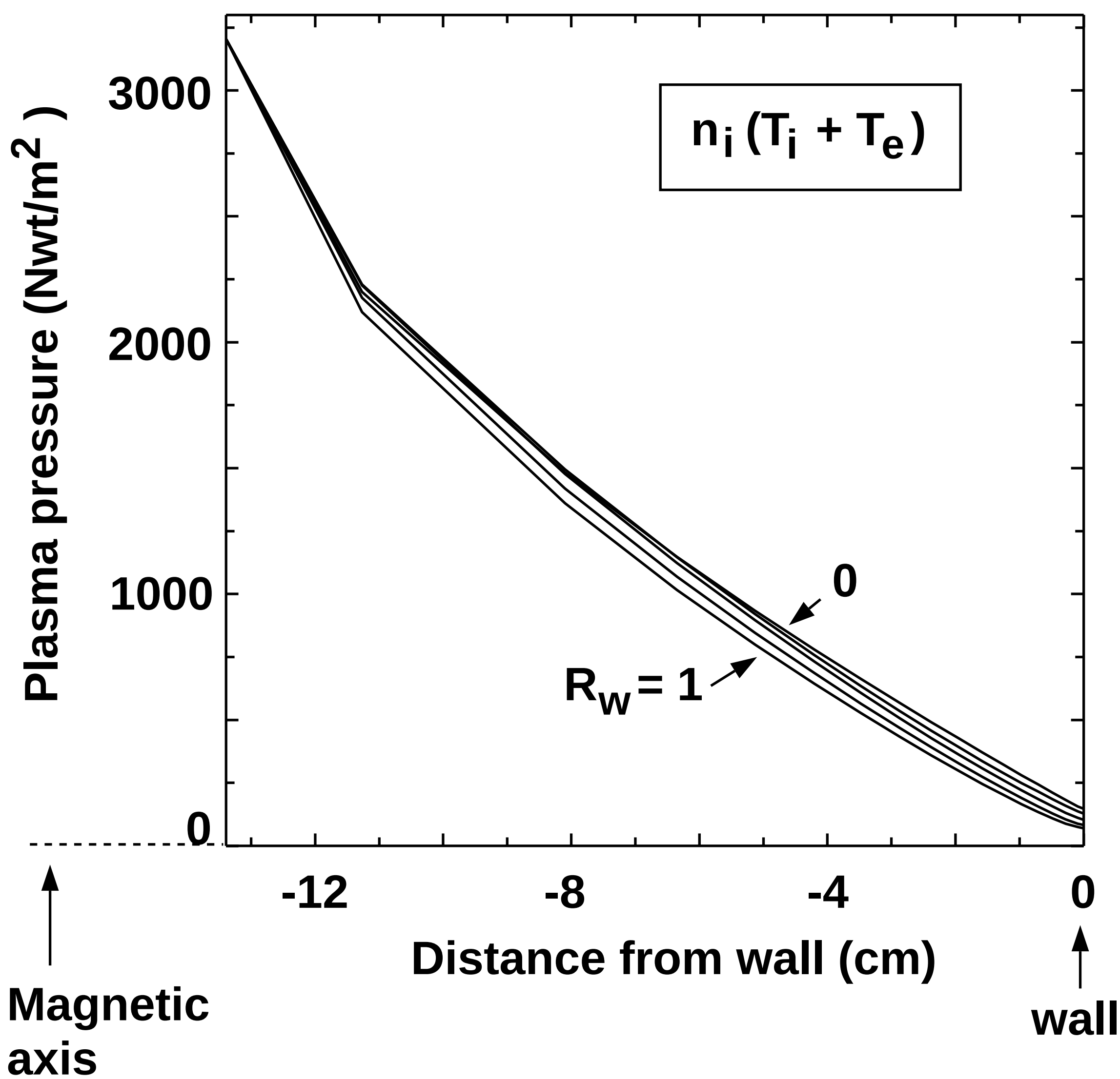


Ion and electron temperatures decrease with wall recycling, Rw

The total plasma pressure, n_i (T_i + T_e), changes little as R_w is varied.



Total plasma pressure, $n_i (T_i + T_e)$, changes little as R_W is varied.



Thick liquid-walled spheromak magnetic fusion power plant

R. W. Moir, R. H. Bulmer, T. K. Fowler, T. D. Rognlien, M. Z. Youssef

April 8, 2002

Abstract

We assume a spheromak configuration can be made and sustained by a steady gun current, which injects particles, current and magnetic field, i.e., helicity injection. The equilibrium is calculated with an MHD equilibrium code, where an average beta of 10% is found. The toroidal current of 40 MA is sustained by an injection current of 100 kA (125 MW of gun power). The flux linking the gun is $1/1000^{th}$ that of the flux in the spheromak. The geometry allows a flow of liquid, either molten salt, (flibe–Li_2BeF_4 or flinabe–$LiNaBeF_4$) or liquid metal such as SnLi which protects most of the walls and structures from neutron damage. The free surface between the liquid and the burning plasma is heated by bremsstrahlung and optical radiation and neutrons from the plasma. The temperature of the free surface of the liquid is calculated and then the evaporation rate is estimated. The impurity concentration in the burning plasma is estimated and limited to a 20% reduction in the fusion power. For a high radiating edge plasma, the divertor power density of 460 MW/m^2 is handled by high-speed (20 m/s), liquid jets. For low radiating edge plasmas, the divertor-power density of 1860 MW/m^2 is too high to handle for flibe but possibly acceptable for SnLi with jets of 100 m/s flow speed. Calculations show the tritium breeding is adequate with enriched ^{6}Li and appropriate design of the walls not covered by flowing liquid 15% of the total). We have come up with a number of problem areas needing further study to make the design self consistent and workable.

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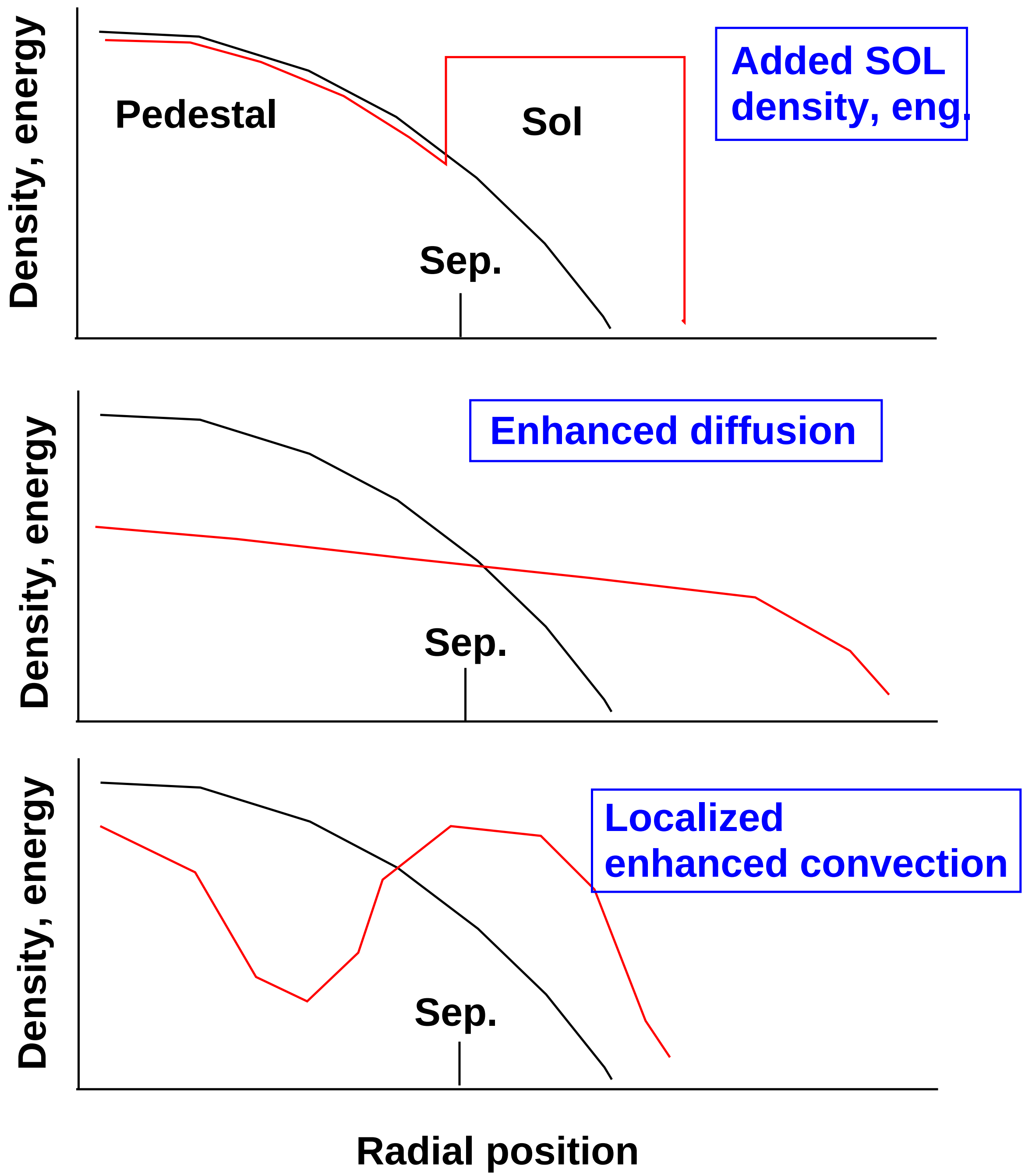
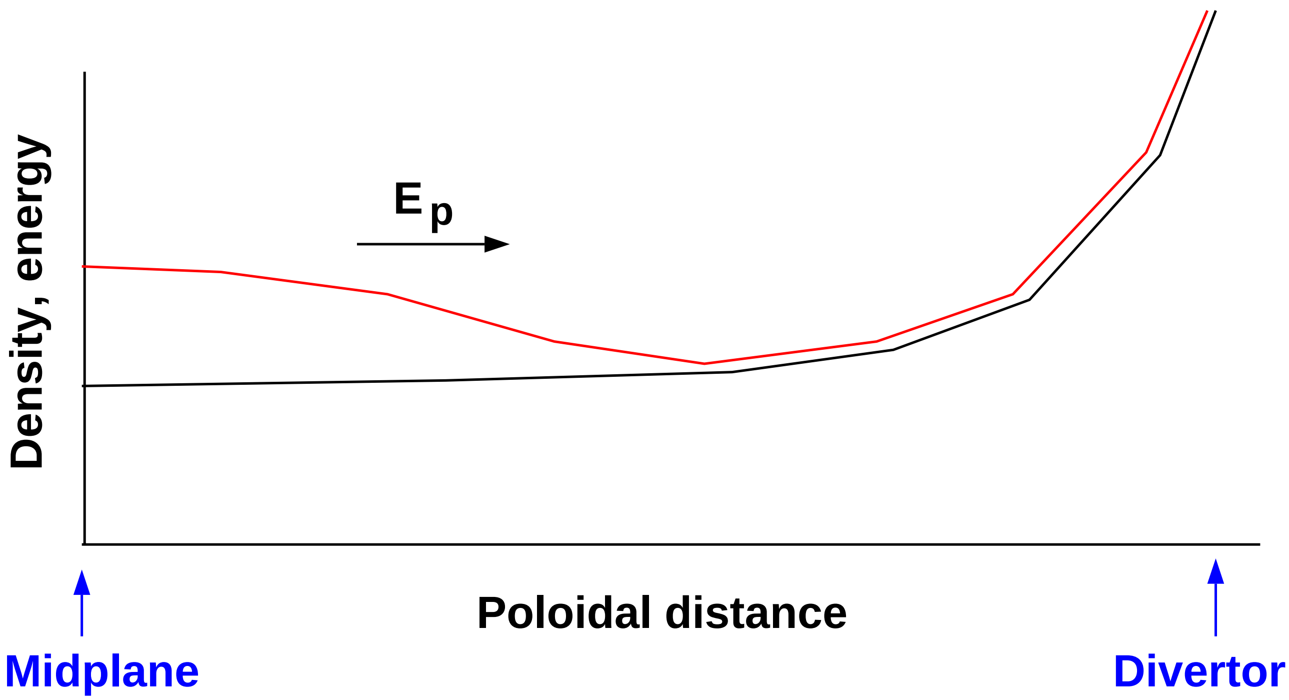
ELM ejection can be modeled various ways



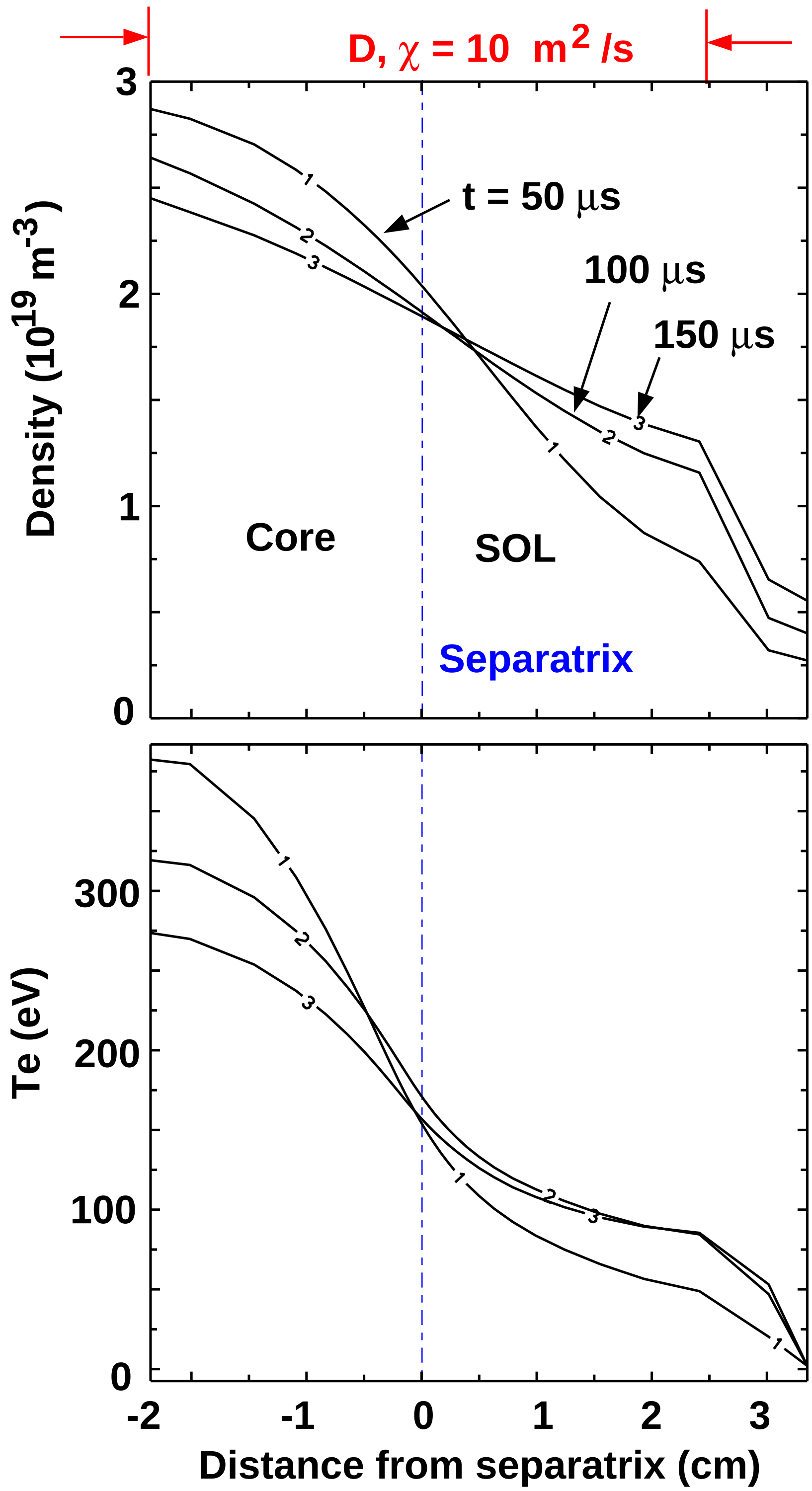
Or 3D turbulence model

Poloidal distribution may also be important



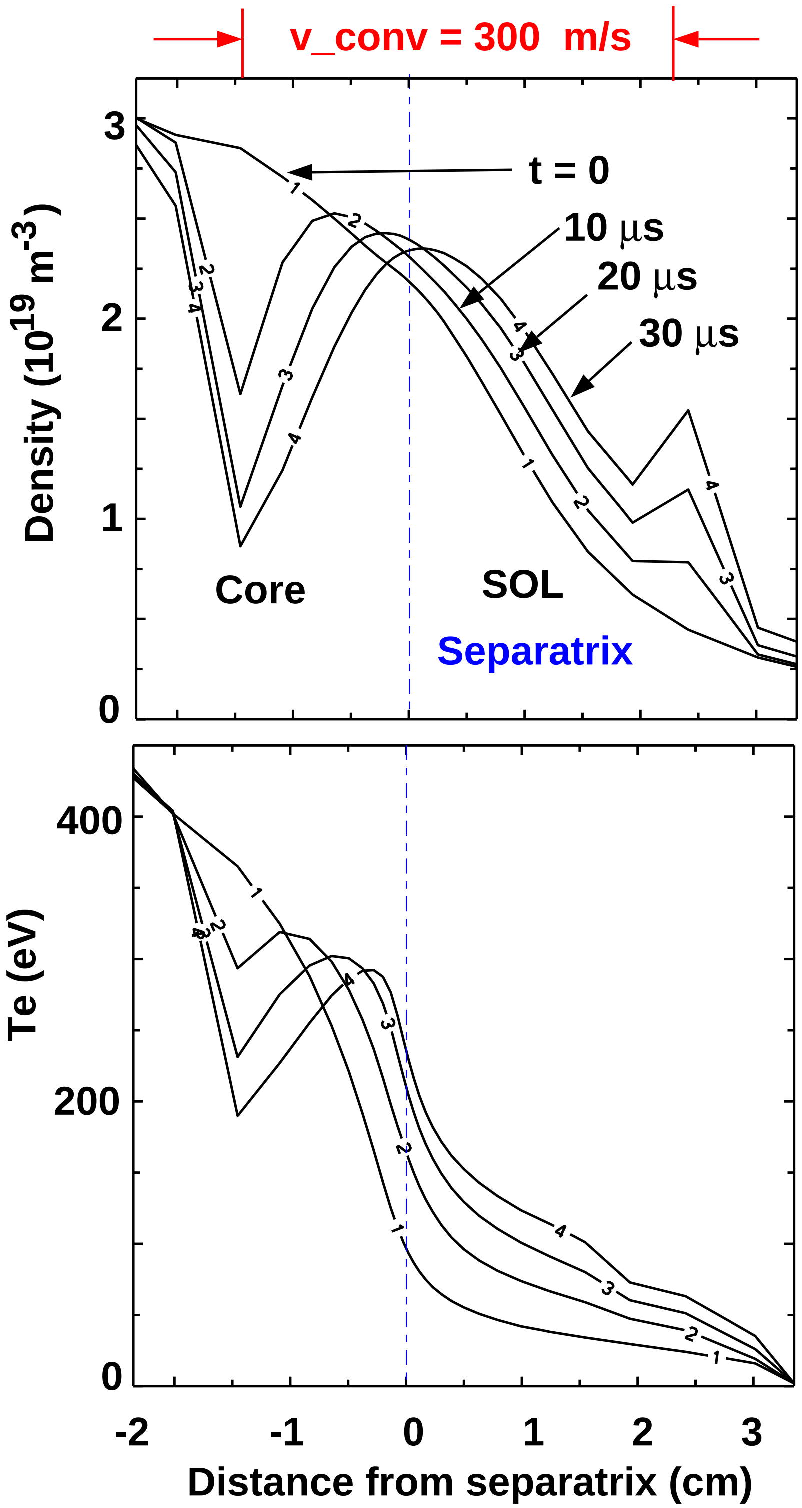
Midplane density and Te profiles broaden into SOL with diffusive ELM model

DIII-D case with s.s. power to edge of 4 MW, ExB on, recycling R=0.99



Midplane density and Te profiles shift to SOL with convective ELM model

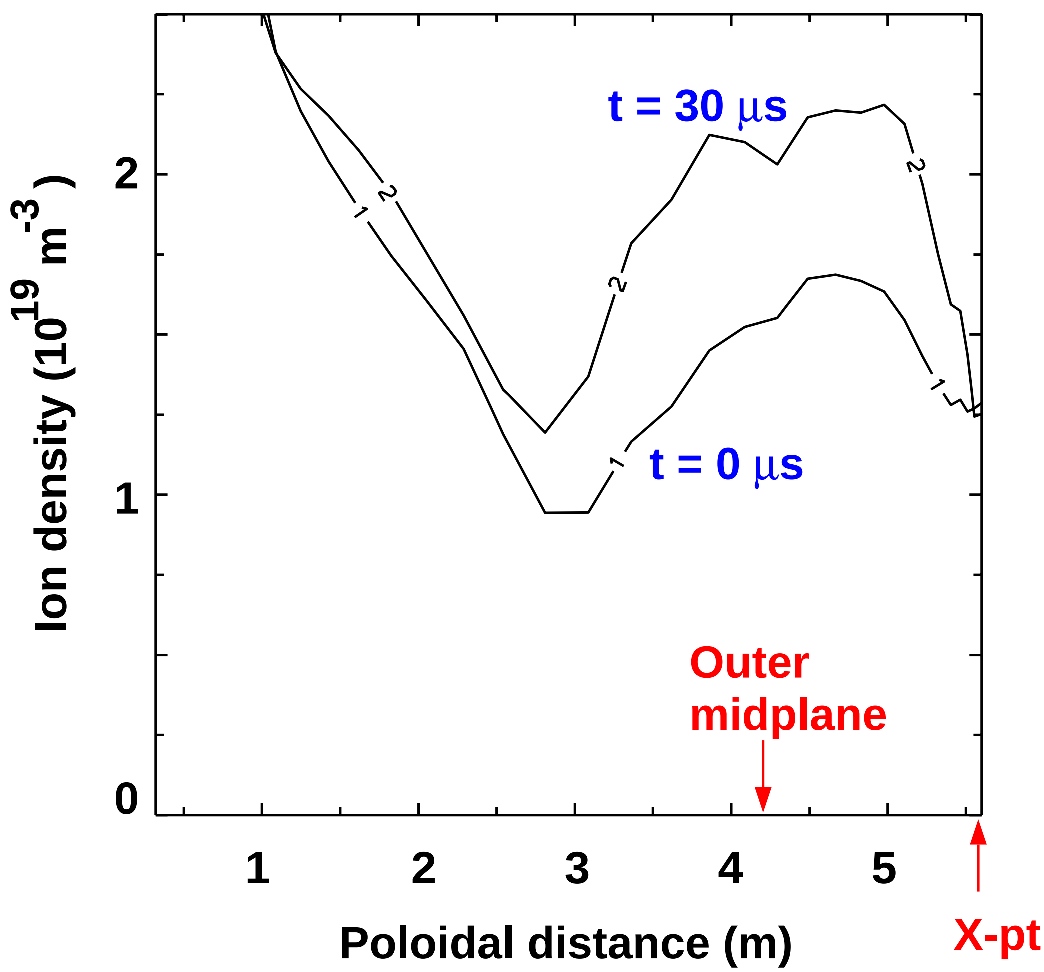
DIII-D case with s.s. power to edge of 4 MW, ExB on, recycling R=0.99



Change in density peaks near the outer midplane during ejection

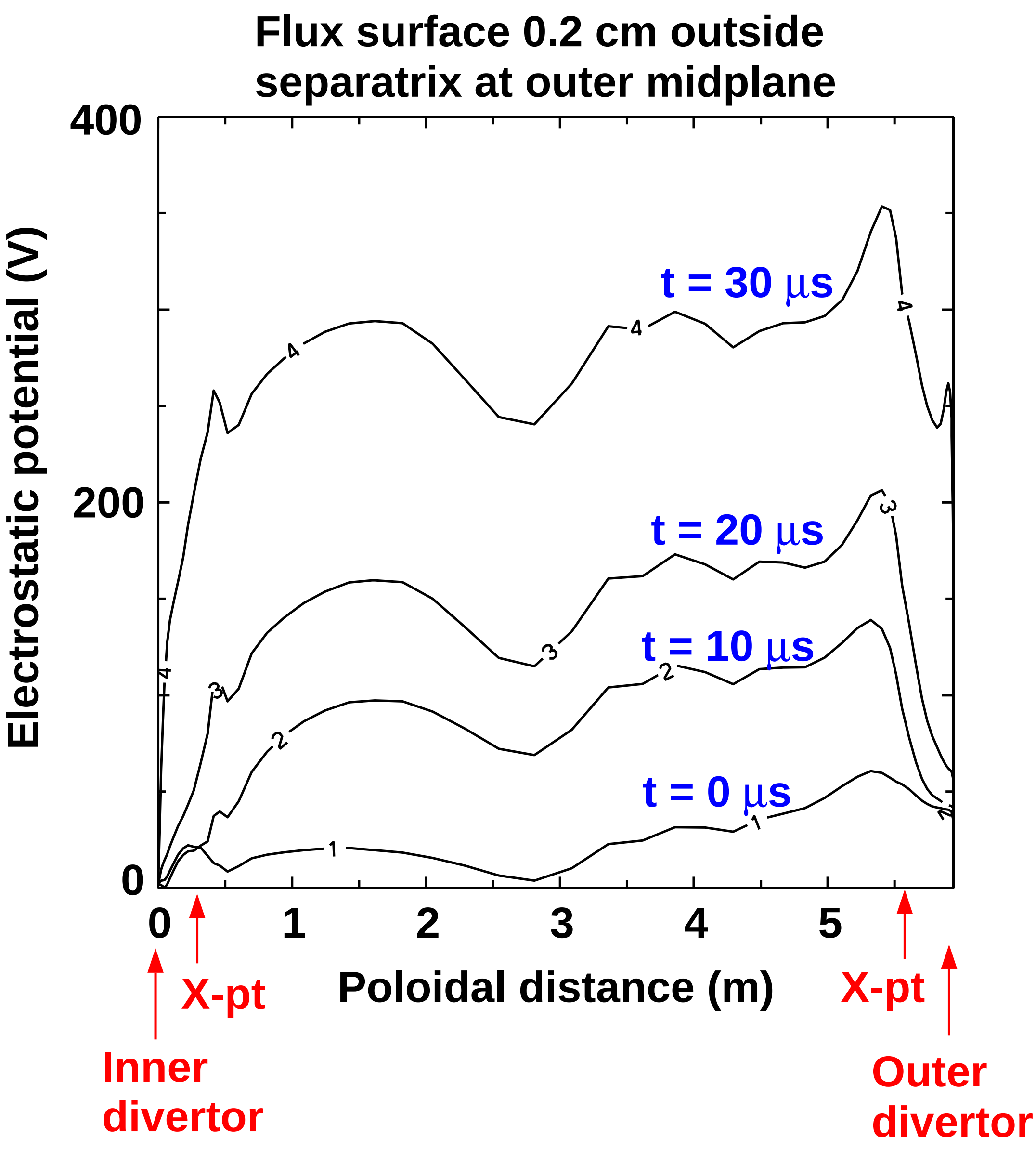
Ejection phase for convective model

Flux surface 0.8 cm outside separatrix at outer midplane



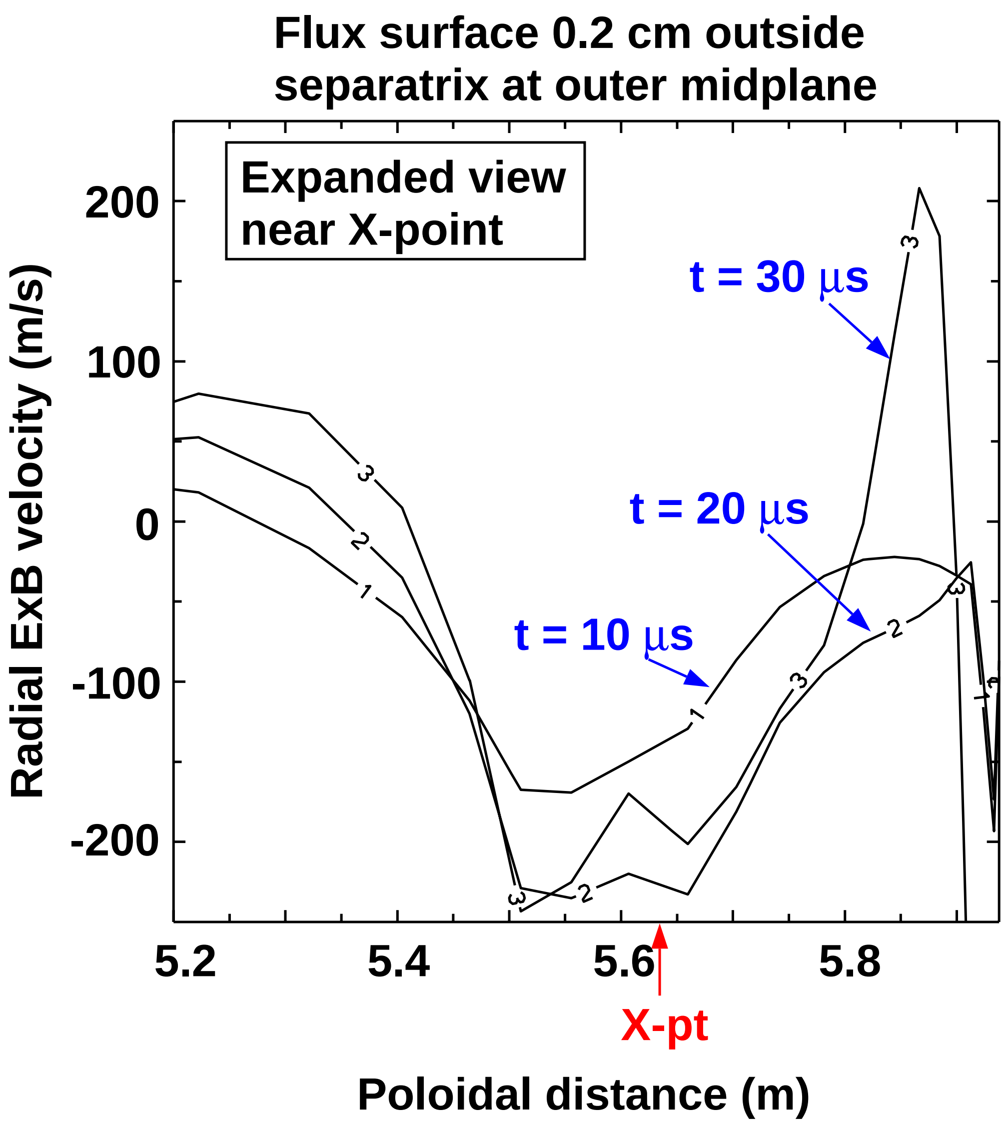
SOL potential rises rapidly as hotter electrons are ejected from core

Ejection phase for convective model



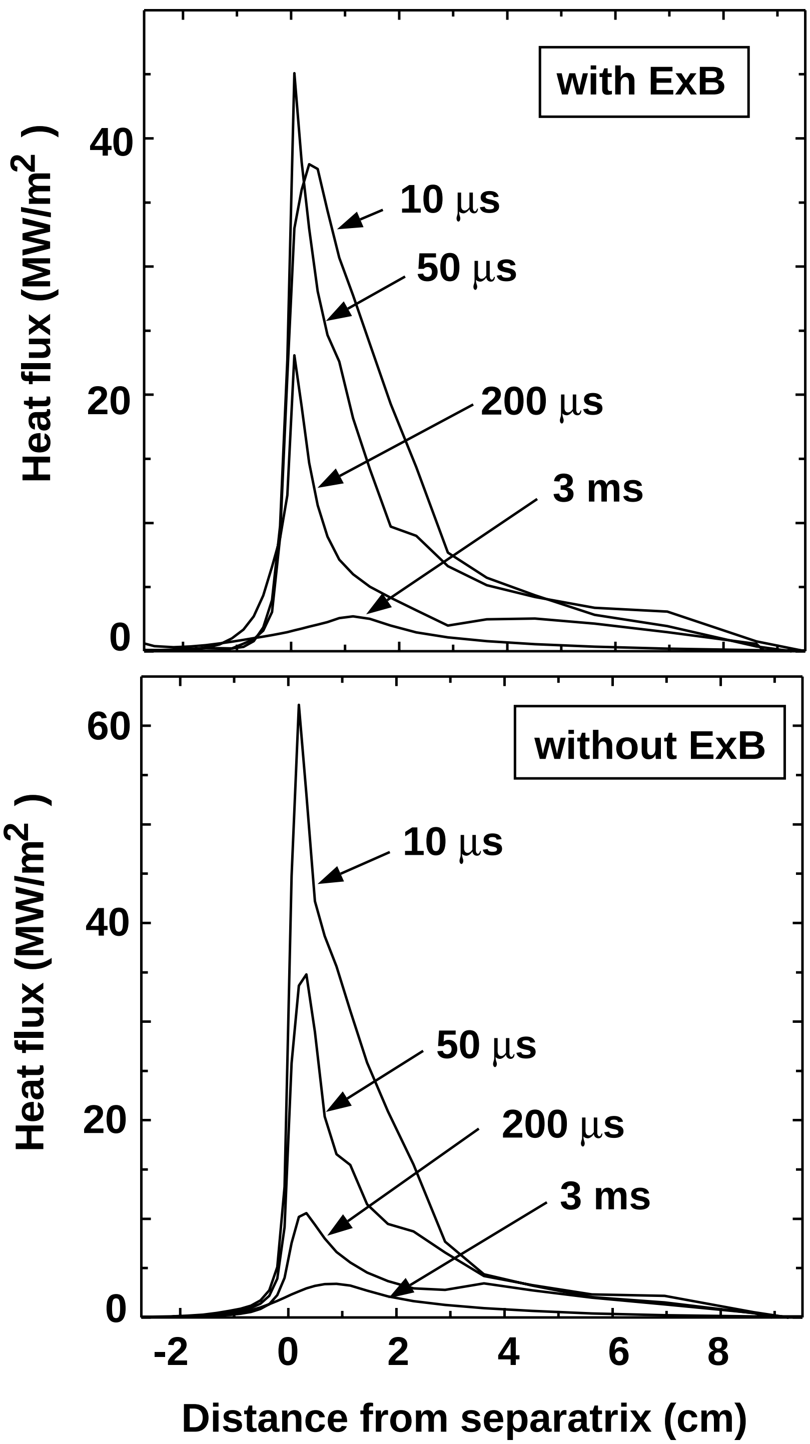
Radial ExB velocity can exceed 200 m/s during the ejection phase

Ejection phase for convective model



Outer divertor plate heat-flux similar with and without ExB terms

DIII-D case using localized convection ELM ejection model
Steady-state power is 4 MW into SOL, recycling R=0.99



Summary

- Convective or diffusive ejection model lead to similar SOL response

- Energy per pulse is important for whether or not inner plate receives significant ELM power

- ExB drifts are strong during the ELM pulse in the divertor leg

    - when starting from same post-ejection state, heat flux profiles are quite similar; larger effect on density

    - comparing ejection phase, ExB case has substantially lower plate density, and longer time-scale for heat flux deposition

- So far, the modeled ELM size has been small; we expect ExB to be stronger for large ELMs and will study these

Summary

Analysis of wall evaporation for flinabe in ARIES (CLiFF) shows surface outlet temperature limits

- 480 C for an orthogonal plate
- 510 C for a tilted plate

Parameter scans for divertor-plasma conditions in NSTX show substantial heat loads & provide input to WBC

Initial full-plasma transport simulations for CDX-U show impact of transition from low to high recycling edge

Characterization of edge-plasmas during ELMs has begun

3D transport simulations with BORIS code will allow non-axisymetric edge assessment for liquid modules

Complete a detailed report for the integration of liquid wall system in a spheromak power-plant